Argonne NATIONAL LABORATORY | Advanced Photon Source

# Advanced Photon Source Upgrade Project

Our nation's success in developing sustainable energy, improving our population's health and protecting our economic security depends on game-changing discoveries and inventions that come from research in new materials and chemical processes. To maintain our competitive edge, we must invest in world-leading research centers—like the Advanced Photon Source (APS) at the U.S. Department of Energy's Argonne National Laboratory—which are critical for these breakthroughs.

As a source of X-rays for research, the APS is extremely successful: More researchers conduct experiments at the APS than any other DOE Office of Science user facility. But solving tomorrow's scientific challenges requires hard X-ray capabilities only dreamed of when the APS was designed and built in the early 1990s. To fully address emerging challenges, **scientists must study real materials in real environments in real time**, which requires penetrating hard X-rays with improved nanoscale spatial and time resolutions.

The APS Upgrade project will equip users for the groundbreaking discoveries and transformational innovations that create new products and industries, generate new jobs, and give our nation a strong competitive edge. It will also **create new high-tech jobs and position Illinois as a high-tech hub for industry**.

The APS attracted more than 5,500 researchers in 2012 from leading companies, research universities, laboratories and federal agencies. They use its intense, highly focused X-ray beams for basic and applied research at the frontiers of materials science, chemistry, medicine, earth and environmental science, life sciences, and many other fields.

## National need

In September 2011, the Director of the DOE Office of Science gave his approval for Critical Decision 1 for the APS Upgrade Project. This formally approves the alternative selection and cost range for the project, establishes the preliminary technical scope, and authorizes a detailed preliminary design and initial research and development report. Pending DOE approval, new capabilities could come online from 2015 to 2020.

## APS key facts

- More than 5,500 researchers a year conduct experiments at the APS, more than at any other DOE user facility.
- Users visit from 73 U.S. companies, more than 200 U.S. universities in all 50 states and the District of Columbia, Puerto Rico, and many federal agencies.
- The 2009 and 2012 Nobel Prizes in Chemistry were based in part on APS research.
- Nearly 5,000 experiments were conducted in 2012.
- More than 10,000 publications are based on research at the APS.

*Aerial view of the Advanced Photon Source.*

## Potential benefits from the APS Upgrade

- More efficient engines
- Solar technologies inspired by biology
- Alternative fuels based on biomass
- Better catalysts for sustainable energy
- Lighter, higher-strength alloys for transportation
- Improved solid-state battery electrolytes, superconductors, data storage and magnets
- Enhanced green manufacturing
- Insights into health and disease effects of metals
- New and improved drugs to fight cancer, AIDS, Alzheimer's, other diseases and conditions
- Remediation of environmental contamination
- New and improved construction and infrastructure materials

## A few APS research highlights

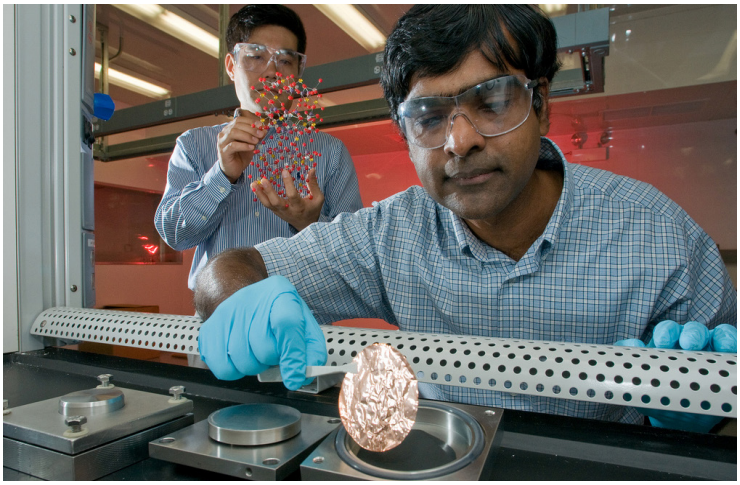
- Kaletra®, a world-leading drug for treating AIDS
- New materials and alloys for medical, electronic, optical and other applications
- DeNOx catalyst that eliminates NOx emissions from diesel engines
- A technique for probing dense liquid sprays that promises cleaner, more efficient engines
- Insight into high-temperature nanomaterials with promising energy applications
- New structural cements that resist sulfate attack

# APS UPGRADE WILL HELP THE NATION KEEP ITS COMPETITIVE EDGE

## Energy

### Electric-car batteries

To make hybrid and all-electric vehicles with good acceleration and a range of at least 400 miles, we need **revolutionary batteries that last longer and store 5 times more energy** than today's lithium-ion batteries. To create them, scientists need to study the nanoscale chemistry that takes place at electrode interfaces inside realistic, operating lithium-ion batteries—something not possible today. The APS Upgrade project will enable this research by increasing the inelastic scattering signal for penetrating X-rays.



*Argonne researchers Sun-Ho Kang andDaniel Abraham assemble a battery for performance evaluation. The APS Upgrade will speed the development of revolutionary new batteries for hybrid and all-electric cars that have good acceleration and a range of at least 400 miles on a single charge.*

### Renewables and electronics

**A new energy technology that uses photosynthesis to harvest sunlight could transform the world** by making cheap energy readily available, even in remote locations in developing nations. Electronics based on photoactive materials could lead to whole new industries and products that create thousands of new jobs. Before they can create these and similar technologies, America's scientists need to understand all the intermediate steps in these complex series of reactions, many of which take place in picoseconds (a trillionth of a second) and involve rapid changes in molecular shape and structure. The APS Upgrade project will provide a tunable beam of intense X-rays uniquely suited to **real-time studies of reactions that take place in the about 1- to 100-picosecond range.**

### Catalyst nanoparticles for sustainable energy

Improved catalysts are critical to creating new sustainable energy and environmental technologies, such as **solar fuels, clean-burning engines and fuel cells**. They are also **used in the manufacture of an estimated 90 percent of all commercial chemical products** and **generate nearly $1 trillion in sales worldwide**. But our ability to improve catalytic processes and invent new ones is limited because we cannot study catalysts in fine enough detail in real time and real working environments. The penetrating X-ray beams from the APS Upgrade project promise to help answer critical questions by providing scientists with the tools to study catalysts in realistic environments that include the presence of catalyst nanoparticles, substrates and chemical atmospheres.

## Materials

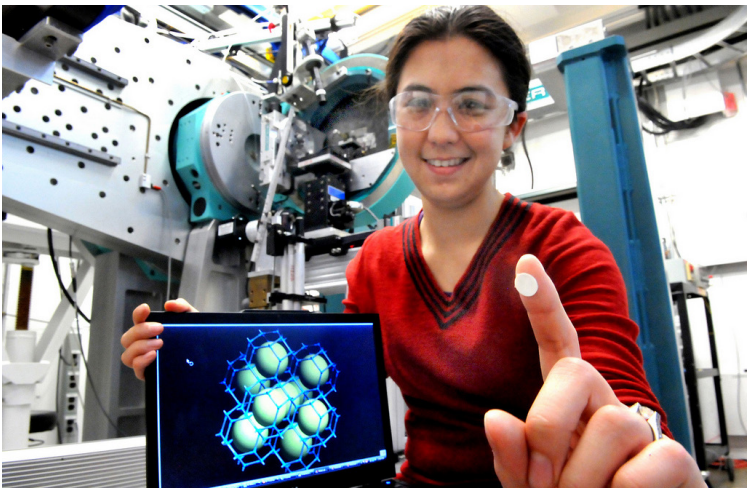
### Designer nanomaterials and molecules

Every sustainable energy technology, from solar cells to advanced batteries to catalysts for clean fuel production, requires scientific breakthroughs at the nanoscale. The ultimate goal is to understand the relationships between structure and function so well that we can design entirely new materials to perform desired functions, then build those materials an atom at a time. To achieve this goal, we need to study materials in real time in all potential complex environments. The APS Upgrade project will provide improved imaging and sample-environment capabilities to study ultra fast reactions in extremes of pressure, temperature, and electric and magnetic fields.

## U.S. industry at the APS

Users from dozens of U.S.-based companies perform research at the Advanced Photon Source. Many have invested millions of their own dollars to equip X-ray beamlines with sophisticated, high-tech instruments to carry out forefront research. Notable companies include:

- 3M
- Abbott Labs
- Amgen
- Battelle
- BP Amoco Chemical
- Caterpillar
- Corning
- Cummins Engines
- Dow Chemical
- DuPont
- Eli Lilly
- Exxon
- Genentech
- General Atomics
- General Motors
- GlaxoSmithKline
- IBM
- Intel
- Merck
- Monsanto
- Northrop Grumman
- Novartis
- Pfizer
- Pratt and Whitney
- Proctor and Gamble
- Rib-X Pharmaceuticals
- Schering-Plough
- Seagate Technology
- Texas Instruments
- UOP
- Westinghouse
- Xerox



*Argonne scientist Karena Chapman holds a wafer of metal organic framework while its structure is displayed on the computer screen. In research at the Advanced Photon Source, she and her colleagues changed the structure of a metal organic framework at pressures low enough for applications such as hydrogen storage for fuel cells.*

### Alloys and composites

High-performance, high-temperature, lightweight and durable alloys and composites contribute to efficient turbines, transportation and other energy technologies by reducing fuel consumption and emissions. But our ability to use them could be greatly improved with a better understanding of how they respond to manufacturing techniques such as the rapid stamping of auto bodies. By allowing scientists to study microscopic stresses in advanced alloys with much greater detail and at faster rates the APS Upgrade project will enable the design of **new metallic alloys for high-performance applications, such as lightweight car bodies, more efficient turbines for jet engines and power plants,** and advanced components for nuclear and clean-coal energy.

### High-pressure and exotic materials

Under high pressure, even simple materials often show unexpected new properties, such as superconductivity, that can lead to new materials for energy and other applications. The APS Upgrade project will increase the pressure and temperature extremes that scientists can study, to test theoretical predictions, such as whether hydrogen can become metallic under extreme pressure.

## Environment

### Carbon sequestration

One strategy for **mitigating global climate change is to capture carbon dioxide emissions and sequester the gas in geological formations**. But keeping it there requires the formation of carbonate minerals over thousands of years, a process that involves chemical reactions between carbon dioxide—both as a gas and dissolved in ground water—and the various minerals in the host rock, all under geological temperatures and pressures. We cannot develop reliable carbon-sequestration strategies until we better understand these fundamental geological processes. New instruments planned for the APS Upgrade project will provide X-ray beams better than those available today and will let scientists watch and record key mineral-liquid reactions in real time under high pressure and high temperature with atomic-level detail.

## Health & life sciences

### The machinery of life

The DOE's Office of Basic Energy Sciences, which funds the APS operations, makes the facility available for non-DOE agencies doing valuable research. As a result, the APS has become a key tool for pharmaceutical and biotech research. The list of new pharmaceuticals derived form APS work includes Kaletra, the most-prescribed drug in its class for AIDS therapy; Zelboraf, to halt the progression of inoperable skin cancer; and Januvia, a diabetes medication. About 70 percent of the drugs on the market target drugs made visible with X-ray lightsources. Biology-focused beam lines at the APS have contributed to information on nearly 80 percent of the protein structures in the global Protein Data Base. Studies of proteins at the APS earned Nobel Prizes in 2009 and 2012 for work that can help scientists pinpoint the best way to fight diseases.

## Leading U.S. research universities at the APS

More than 250 universities from all 50 states and the District of Columbia have conducted research at the Advanced Photon Source. Examples include:

- Columbia
- Cornell
- Duke
- Harvard
- Johns Hopkins
- MIT
- Northwestern
- Ohio State
- Princeton
- Stanford
- University of California
- University of Chicago
- University of Florida
- University of Illinois
- University of Michigan
- University of Minnesota
- University of North Carolina
- University of Pennsylvania
- University of Southern California
- University of Texas
- University of Washington
- University of Wisconsin
- Vanderbilt
- Washington University
- Yale

U.S. DEPARTMENT OF ENERGY

Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

## Federal research at the APS

More than a dozen federal agencies and institutions depend on the Advanced Photon Source in pursuit of their missions, either by funding research at the APS or by conducting their own research as APS users.

**Funders**

- Centers for Disease Control and Prevention
- Department of Agriculture
- Department of Defense
- Department of Energy
- Environmental Protection Agency
- National Aeronautics and Space Administration
- National Institutes of Health
- National Science Foundation

**Users**

- Department of Energy
- Department of Defense
- Environmental Protection Agency
- National Aeronautics and Space Administration
- National Institute of Standards and Technology
- National Institutes of Health
- Smithsonian Institution
- U.S. Geological Survey

## Maintaining our competitive edge

The APS Upgrade project will help the United States maintain its international competitive edge while improving our quality of life, promoting long-term economic growth and answering fundamental questions in materials physics, chemistry, and many other fields. Currently, 73 U.S. companies, more than 200 U.S. universities, and many government agencies have user agreements with the APS. All of them are playing important roles in shaping the details of the upgrade.

## Synergy with other Argonne facilities

The APS Upgrade project will greatly enhance synergies among Argonne's existing user facilities and research programs, all of which are located within a one-mile radius.

- **The Center for Nanoscale Materials** is a regional center for basic and applied research on nanoscale materials. Its portfolio includes energy-related research and development programs.
- **The Argonne Leadership Computing Facility** provides leadership-class computing resources to the national scientific community.
- **The Structural Biology Center** operates a national user facility dedicated to understanding the structure and function of large biological molecules important to energy resources, health, a clean environment and national security.
- **The Electron Microscopy Center for Materials Research** develops and maintains unique capabilities for electron beam characterization and applies those capabilities to solve materials problems.
- **The Transportation Technology R&D Center** brings together scientists and engineers from many disciplines to find cost-effective solutions to the problems of transporting people and goods from one place to another — issues like vehicle emissions and energy supply.

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